International Journal of Science and Research (IJSR)
ISSN: 2319-7064
ResearchGate Impact Factor (2018): 0.28 | SJIF (2018): 7.426

Review of the Nile Delta Conditions since 1984 under persistent Urbanization

Abdulmoneim Alfiky[1], Mohamed Salheen[2]

[1,2]Urban Design & Planning Dept., Faculty of Engineering, Ain Shams University, 1 Sarayat St., Abassia, Cairo, Egypt

Abstract: ***The Nile Delta- the last stretch of the world longest river and home of one of the oldest and most fertile agriculture regions of the world- has suffered in the past five decades great losses to its agricultural mass. This loss was induced by massive urban sprawl movement and land-use transformation. Though various legal and regulatory tools were used by the different Egyptian governments to combat this issue and preserve the existing priceless agricultural land, the sprawl has persisted through the decades at a varying pace. Currently the Nile Delta is suffering from massive fragmentation to its fabric by the extensive and condense urban network spreading over it along with an obvious soil deterioration and loss of agricultural productivity brought upon by the considerable influx of pollutants generated from this network. This paper presents a review of the status of the Nile Delta in all its natural & man-made aspects the amount of urban growth since 1984 till 2018: monitoring the rates of urban growth, their patterns and its overall perceived effects on the region.***

Keywords: Nile Delta, LUCC, Agricultural Fragmentation, Change Detection, Urban Expansion, Expansion Patterns, Land ownership, Envi, ARCGIS.

1- Introduction

Deltas are unique fragile existences on the face of our planet. They are the preferred human habitat worldwide with rich biodiversity, high productivity and ease of transport. They carry a lot of potential both ecologically and economically. And they face many dangers due to over exploitation of our planet. [1], [2]

River systems and coastal regions are considered favored human habitats. About 60 % of the world population is concentrated along them. And while globally deltas only cover 0.56% of the total area of the world, they house 4.1% of the global human population, estimated at around 300 million in 2017 and projected to reach 322 million by 2020 with a population density of 422 inhabitant/km2 as compared to the projected world population density of 60 inhabitant/km2. [3]–[5]

In Egypt most of the population reside around the fertile lands on the Nile Valley and Delta – which forms only 7.8% of the total area of the country -with an alarmingly high population density reaching 1,218 inhabitants/km2. Around 58% of the population live in rural areas although a relatively small percentage of the working force are employed in the Agriculture sector. [5]–[9]

The agriculture land is divided into arable lands and permanent crops with 74.6 % & 25.4 %, respectively (2016). It consumes 86% of available water in irrigation as compared to 3% for industry and 11% for municipal use (2010). And despite Egypt's large rural population, as of 2016, only 25.6% of the active working force works in the agriculture sector that accounts to 11.13% of the GDP and with 50% of agricultural holdings being less than 1 feddan (0.42 hectares). [7], [8], [10], [11]

With the high population density, high demand for land for residential & service uses, and the shaky economy of the agriculture sector, the appropriation and conversion of fertile agricultural land is understandable. Based on the land consumed by urbanization in the past decades, some studies projected that before end of the 21st Century all prime agricultural land in the Egyptian Valley & Delta will be lost.[8], [12]–[17]

Based on the State of the Environment Reports by the Egyptian Environmental Affairs Agency EEAA –from unpublished records of The General Directorate for the Protection of Land– the agricultural land loss from 1983 till 2016/2017 was measured at 403,900 Feddan, and could be categorized as; 45% illegal encroachments, 14% legal appropriation for public & private use, and 41% expansion of the urban boundaries of cities & villages. [18]

2- Review

2.1- Basic Geomorphological Structure

The Nile River is the largest river system in Africa with a drainage basin that spans an area of ~ 3.03 million km^2. It starts at Lake Victoria in east central Africa, continues north into Egypt till it drains in the Mediterranean Sea after crossing 6645 km in its journey. The Nile Delta (Fig 1) is the last stretch of the river. It is one of the oldest deltas of the world. The shoreline is cuspate at the mouth of the distributaries; with shore-parallel beach ridges and 3 large lagoons occurring between them which are from west to east; Lake Idku, Lake Burullus, and Lake Manzala respectively. It has two distributaries: the Rosetta and Damietta branches. [19]–[23]

The delta stretches for 160 km from south to north and 240 km at the coast from west to east. It covers an area of ~ 22000 km2. The terrain is flat with a very gentle slope with a variance of only 12 m from Cairo in the south to the Mediterranean coast in the north. The silt soil of the delta is considered the most fertile in Africa. And while globally the fertile topsoil is measured at just few centimeters, the topsoil in the delta averages 11 m in thickness with the northern regions reaching up to 20 m. [12], [19]–[23]

2.2- The Human Habitat

2.2.1 Policy & Law

For the past two centuries the Nile Delta has experienced a series of rapid changes that directly contributed to its current condition. In the 1800s; the massive redesign of the waterways and waterworks in Egypt, introduction of new crops e.g.: cotton & sugar cane, grown mostly for their economic value as exports, consolidation of ownership resulting in the creation of massive holdings. But while those changes brought a lot of improvement to the agrarian economy, it also brought many hardships to the peasants; conscripted labor under terrible working conditions, enforced crop patterns with enforced pricings, no social security or insurance of any sort. [7], [24]–[28]

The hardships faced by Egyptian farmers & peasants in that period was the main motivator behind the drastic measures taken by the 1952 Revolution that aimed at redistributing the wealth in Egypt to achieve social justice and equality. And towards that endeavor, the government made into law several legislations. First, Agricultural Land was confiscated by the state from its owners leaving only between 100 to 200 Feddans to each original owner and then redistributing the remaining land among the originally land-renting farmers and hired peasants at a rate of 2 to 5 feddans per household. Effectively the law created a case of fragmented ownership that coupled with the inheritance laws in Egypt that allows for subdivision of all assets between first degree relatives (and in some case second degree relatives as well) would only allow for the fragmentation to worsen through the following generations. [17], [24], [28], [29]

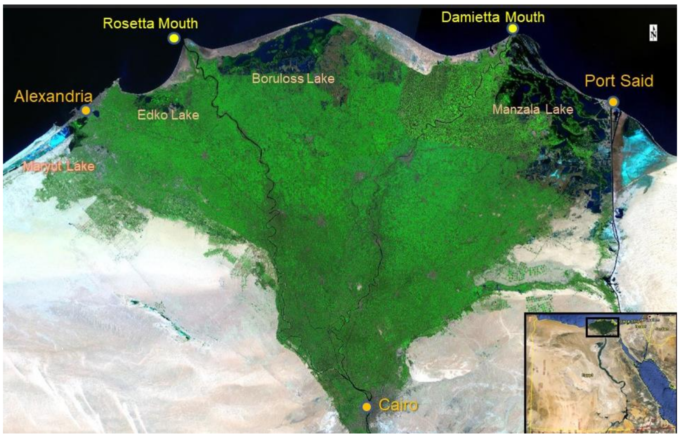

Fig 1: Area of Study "The Nile Delta"
Landsat composite image of bands 7-4-2 "Natural-like Rendition" [SWIR 2 (Short Wave Infra-Red 2) (7), NIR (Near Infra-Red) (4), Green (2)] Healthy vegetation appears in bright green, pink areas represent barren soil, oranges & browns represent sparsely vegetated areas, water appears in blue and Urban areas appear in varying shades of magenta. - Based on [30]

Second, several laws and decrees defining the relationship between the owner and renter for residential property was also released in 1952, 1958, 1961, 1962 and 1965, collectively known as the rent value reduction laws (or rent control laws). Those legal amendments started by lowering the established rents prior to the revolution by 15% then those rented between 1952 & 1958 by 20% and then all rent contracts that was subject to the 1952, 1958, & 1961 laws by another 20% (of the lowered value) and all those subject to the 1962 law by 35%. And finally, the right of the owner to determine the amount of the rent was revoked by the government in favor of local municipal committees that investigated individual cases and established the rent amount. Added to that, the renting contract duration limitation was removed effectively making the contracts life long and then allowed the contract to be moved to the next of kin of the renter by inheritance.[31]–[36]

Then in 1961, a nationalization decree was established effectively bringing all companies and firms under state control including agricultural firms. And in 1969, a law was passed to halve the previously stated ceiling on agricultural land ownership to 50 Feddan for single individuals and 100 for the whole Household. [17], [37]

Under the influence of all these laws massive changes took place in both the agricultural sector and the real-estate markets. agriculture landowners with renter on their land lost all economic feasibility in retaining their land. Which pushed them along with those who retained farms of too small a size to look for more lucrative ways in using their lands. At the same time, real-estate developers to move from rent market into the ownership market which ultimately created a shortage in housing for the low & middle segment of the market. As a result of all that, converting agricultural land into source for soil for fire-clay bricks and altering its use to build small sized affordable housing became the new profitable endeavor. This resulted in massive loss of agricultural land across the country and with the conversion of land into urbanized use, the population density progressively increased. That meant more services needed and in turn more land taken to accommodate those services. [38], [39]

With how sever the problem became, the government started taking measures to stop the land loss. For the 1978, 83, 85, & 96, the focus was on punitive measures. And while somewhat effective in curbing the rate of loss, those measures were not successful in stopping it entirely as no suitable solution for the housing problem was present and no recourse for the lower profitability of small farms was offered. [39]–[43]

The early 2000s, came with a shift in the governmental policies as revitalization plans came into the picture. With the aim to study the needs of villages in housing & services and offer them, the strategies continued to ignore the underlying problem with agricultural profitability. Meanwhile, the agricultural land legally appropriated for those plans rose to match the land that was illegally encroached upon since 1983. [12], [39], [43]

Part of the pressure facing the agricultural land and leading to its appropriation to urban use (both legally and illegally) in the delta is related to how densely populated it is.

Currently it hosts an average population density over 44 times the world average with almost two thirds of the Delta population residing in rural areas. [5], [8], [9]

By 1952, (**Error! Reference source not found.**) 94.3% of holdings/owners owned 35.4% of all agricultural land in Egypt in holdings that were 5 feddans or less, while 0.09% of the owners owned 19.7% of all land in holdings starting from 200 feddan to well over 2000 feddan. Following the agrarian reform in 1952, the area of holdings of 5 feddan and less increased to 46.5% of total area of farms and accounted for 94.4% of owners while holdings of 50 feddan to over 200 feddan accounted for 20.3% of the area and 0.4%of the owners.

Table 1: Land Holdings in Egypt from 1952 till 2010
Adopted and calculated from [17], [43]

Land holding category (Feddan)	Before Agrarian Reform 1952	
	Holdings (%)	Area (%)
<5	94.3	35.4
5-10	2.8	8.8
10-20	1.7	10.7
20-50	0.8	10.9
50-100	0.2	7.2
100-200	0.1	7.3
200-800	0.08	9.92
800-1000	0.003	1.45
1000-1500	0.004	2.05
1500-2000	0.001	1.63
2000+	0.002	4.65

Land holding category (Feddan)	After Agrarian Reform 1952	
	Holdings (%)	Area (%)
<5	94.4	46.5
5-10	2.6	8.8
10-20	1.6	10.7
20-50	1	13.7
50-100	0.2	7.2
100-200	0.1	7.2
200+	0.1	5.9

Land holding category (Feddan)	At The nationalization Acts 1961		Land Ownership Ceiling 1969		In 2000, after the law of land holding liberalization	
	Holdings (%)	Area (%)	Holdings (%)	Area (%)	Holdings (%)	Area (%)
<5	94.1	52.1	95.8	56.3	90.4	47.8
5-10	2.6	8.5	2.3	9.7	6.3	15.6
10-20	2.1	10.6	1.1	9.8	2.2	11.8
20-50	0.8	13.5	0.5	9.2	0.8	10.3
50-100	0.2	7.1	0.2	6.5	0.2	4
100+	0.2	8.2	0.1	8.5	0.1	10.5

Land holding category (Feddan)	2010	
	Holdings (%)	Area (%)
<5	91.69	49.6
5-10	6.76	17.4
10-20	1.01	7.21
20-50	0.5	8.06
50+	0.04	17.73

** 1 Feddan = 4200 m2 or 0.42 Hectares*

Then following the second agrarian reform in 1969, the areas of feddan or less increased to 56.3% and accounted for 95.8% of the owners while holdings of 50 feddan to over 100 feddan accounted for 15% of the area and 0.3% of the owners. In 2000 with the start of the revitalization plans, farms of 5 feddan and less dropped to 47.8% of total area and 90.4% of owners while farms of 50 feddan to over 100 almost maintained their size at 14.5% of the total area and 0.3% of the owners. In 2010 at the end of the revitalization plan period, farms of 5 feddan and less accounted for 49.6% of the area and 91.69% of the owners while farms of 50 feddans and more accounted for 17.73% of the area and 0.04% of the owners. [17], [24], [27], [28], [43], [44]

2.2.2 Demographic Structure

Starting downstream from Cairo and going north to the coast, the Nile Delta spreads across 9 governorates that has 84 local municipalities, 99 cities, 642 main villages, and 1977 satellite villages and hamlets holding in 2018 over 45 million inhabitant representing ~11 million families with ~ 64% living in rural areas and an average population density of 2064 inhabitant/km2 across the entire agrarian area of the Delta. The labor force in the delta represents almost 50% of Egypt's total labor force. Those employed represents around 88% of the labor force with those employed in Rural area being 66.49%. [8], [45]

Across Egypt, those working in the agricultural fields are in constantly diminishing, in 2016 they were around 26% of the total labor force contributing ~ 11% to the GDP; in 2011 they were for ~ 29% that contributed ~ 15% to the GDP, in 2003 they were ~ 31% of the working force contributing ~ 17% to the GDP. Whereas in 1983, they were ~ 38 % of the active working force contributing ~ 19%of the GDP.[8], [46]–[49]

2.2.3 The Egyptian Village

The built-up fabric of an Egyptian village starts with the old core of the village initially constructed prior to the 1950s; a dense organic fabric with narrow roads between 2-3 m usually with closed-ends and unevenly sized building parcels with 1-2 stories wall bearing mud houses. During 1980s through end of the 20th century, most of the buildings in this zone was rebuilt as concrete skeletal structures and the heights extended to upwards of 5 stories with no alteration to street width. [43], [50], [51]

The expansion on the core zone of the villages started through subdividing existing agricultural troughs (semi-rectangular plots divided based on ownership and irrigation/drainage networks) in the immediate surrounding of the village and selling them as building plots some with areas as small as 20 m^2. The expansion took one of three forms; linear fabric in the mid-1970s directly surrounding the **"*Daier El-Nahya*"**, the uncompleted blocks in mid-1990s where the built-up area stretches along the road networks to nearby settlements or along existing canals and drains, and the scattered fabric that appears on the fringes of expansion zone and represent a form of new nodes\cores for new expansions. [43], [51]

In the expansion zones, the building heights tend to be 4-5 floors with concrete skeletal structure. The road networks are usually more regular with no closed-ends and relatively wider up to 6 m. The services would be scattered along those internal roads or along the main roads connecting to nearby settlements. And due to the lack of open public spaces as compared to the core zone, the internal road network carries the function of social gatherings, children playground, and even animal breeding. [43], [50], [51]

With the narrow streets; little or no maintenance, no clear hierarchy, and 40.5% of all villages having encroachments on their streets, the villages experience difficulties in accommodating vehicular traffic and the accessibility &

coverage of emergency services are at best questionable. [50]–[52]

Buildings lack enough natural ventilation & lighting and usually exhibit bad distribution of house elements. With no façade paintings, they typically have low visual standards. The buildings also, exhibit lack of maintenance which could lead to lower structural integrity, i.e.: of all Egyptian villages, 61% have buildings that show water damage due to bad plumbing. [50]–[52]

86.7% of all villages have irrigation or drainage canals passing through them. In 44% of those villages, the banks of the canals are wrecked. In 26.9% of them, the bridges across the canals are broken. And with an Inefficient waste collection and disposal system in villages, 71% of those villages have garbage in their canals, and 44% even have dead animals disposed in the canals. [50]–[52]

The villages also experience a shortage in education, health and recreation services; 59.4% of all villages need schools, 40.5% need a primary health clinic, and one third needs cultural clubs, bakeries, youth centers, and literacy classes. [50]–[52]

As for infrastructure, the situation is rather varied and complex. 97.5% of all villages have most of its buildings connected to the general electricity network. The service though is intermittent with 15.4% of villages having mostly stable service while the rest experience power outage at various intervals; some weekly, while others daily. [52]
Fresh water supply covers most building in 96.5% of all villages. 72.5% experience outage in service on varying intervals from daily to each week. As for sewage networks, 74.3% of all villages are not covered. And the villages that are, have network blockage in 52.6% of them. [52]

2.3- Agricultural Aspect

2.3.1 The Agrarian Economy

In Egypt, the share of Agrarian economy to the National economy has been steadily declining over the past few decades in respect to; its share in the national GDP, its share in total national investments, and in the percentage of the labor force working in that sector. [8], [46]–[49]

Meanwhile, food imports are steadily increasing, agricultural land per capita is decreasing, and along with that progressive decline in the agricultural sector an odd phenomenon is emerging where villages with no one working in the agrarian sector emerge. [7], [47], [48], [53]

Egyptian farms are characterized by highly intensive production, fragmented farm patterns, low share of owned physical capital, labor-intensive techniques, high dependence on the use of fertilizers, and high reliance on Nile water for irrigation. [17], [47], [48], [54]–[57]

2.3.2 Soil Salinity

Soil salinity is a main issue in the Nile Delta with almost 100 Kg/feddan accumulated salt in the soil yearly. The problem is mainly caused by:[19], [22], [23], [55], [58]

- Perennial irrigation using an extensive irrigation network and a deficit field drainage system.
- The extensive reuse of agricultural drainage water in irrigation to compensate for the lack of enough water resources.
- Excessive withdrawal of groundwater resulting in enormous drops at the ground water level and leading to sea water intrusion which is more apparent at the northern parts of the region around the north lakes.

Since the mid-1980s till the end of the 1990s, massive undertaking has been put forth to control soil salinity including extensive rice cultivation in the northern regions and an extensive overhaul of in-field drainage systems across the Delta with subsurface drainage. [55], [58]

Subsequently, soil salinity has improved across the delta and is considered under control with the use of precise control of water reuse through the mathematical model SIWARE that is used to divides the delta in calculation units CU to estimate the needed reuse water to maximize productivity while controlling levels of soil salinity. [59]–[62]

2.3.3 Land Productivity

A review of the productivity grades across the local municipalities of the Delta from 1981 till 2015 (Fig 2) shows great fluctuations from one study interval to the next. In the interval from 1981-85 to 1986-90, 98.6% of all local municipalities show severe drop in their productivity grades. From 1986-90 to 1990-95, only 18.9% of municipalities show slight decrease in their productivity while the rest show significant improvement.

towns and villages upstream that directly or indirectly drains in the river. [7], [8], [55], [58], [62]

The high dependency on irrigation resulted in the creation of an extensive irrigation network – ~ 40,000 km in the Valley & Delta –that was designed and established during the early 1800s and 1900s (*Fig 3*). Water flow through this network is highly controlled through dams & barrages across the valley

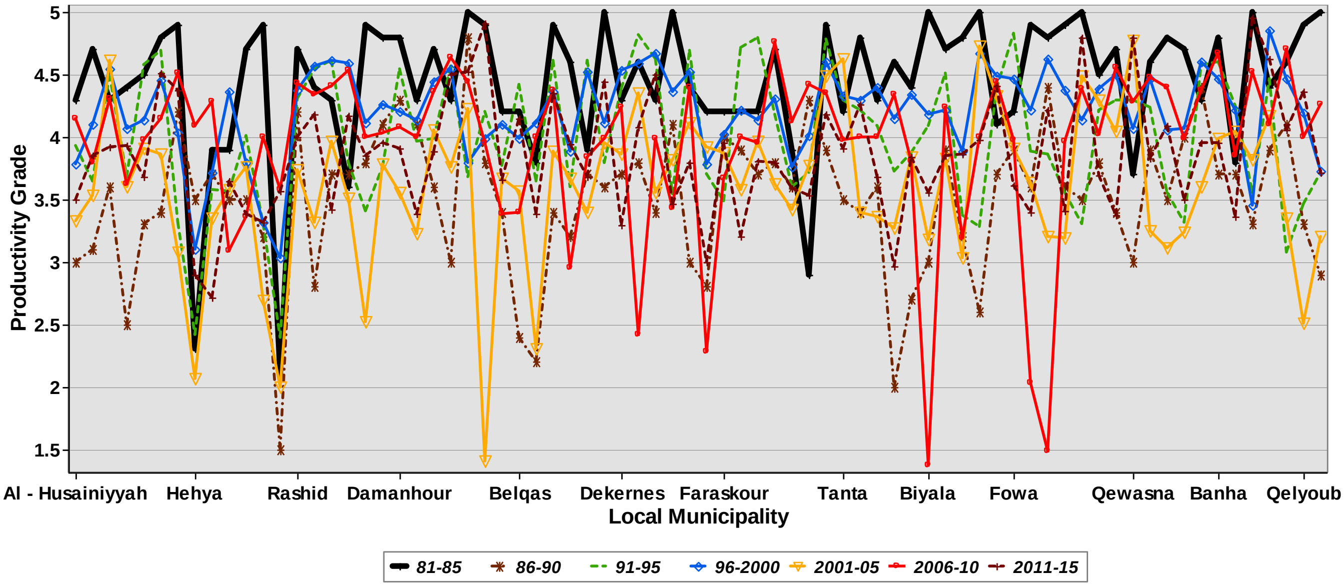

Fig 2: Productivity Grades of the Nile Delta between 1981 & 2015 [63]–[69]

and delta and yet due to the low efficiency of the network, water loss is estimated at around a fifth of the yearly renewable resources. [7], [48], [55], [62]

From 1990-95 to 1996-2000, 28.4% show slightly decreased productivity while the remaining municipalities show mild increase. From 1996-2000 to 2001-05, another severe drop in productivity shows across 89.2% of municipalities. From 2001-05 to 2006-10, 31% show decrease in productivity while the rest of the municipalities show varied improvements. From 2006-2010 to 2011-2015, 63.5% of all municipalities show varied decrease in their productivity grades. Overall the 1981-85 interval remains the highest in its productivity grades across all municipalities as compared to all subsequent intervals. When comparing the 2011-15 interval with it, 86.5% of all local municipalities show lower productivities than 1981-85. [63]–[69]

With the introduction of high productivity crop varieties with more intensive production methods along with the improved in-field drainage and overall lower soil salinity better results in the agricultural productivity of the Delta region should have shown .[55], [59], [62] Alas, productivity grades show fluxes with severe drops in the late 1980s & early 2000s. And despite all the measures taken to ensure an increase in productivity, the highest productivity grades show in the early 1980s.

2.3.4 Water Resources & Uses

The Nile has been the main water source for Egypt, the Valley & Delta directly consume around 81% (~ 62 billion m^3) of the yearly water budget for agriculture. The water quality is affected by many factors in its journey downstream; a) drainage water carrying salts, fertilizers, pesticides, herbicides; b) industrial & domestic sewage from

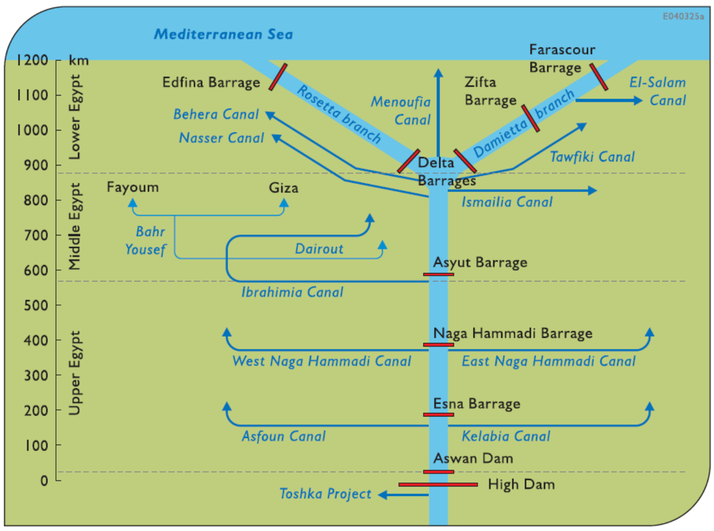

Fig 3: Schematic of The Dams, barrages, main canals on the Nile System [55]

This lower efficiency could be attributed to the distorted cross sections of the canals (*Fig 4*) that leads to wasting more water trying to ensure that a steady water flow would reach their ends. [70]

Corresponding to the irrigation network is a massive and extensive drainage network (*Fig 5*) that starts at the fields and aim to move drainage water all the way to the

Mediterranean Sea. Water for reuse is recycled from that network by mixing it with fresh irrigation water and reintroducing it to fields downstream. [7], [47], [56], [60], [71]

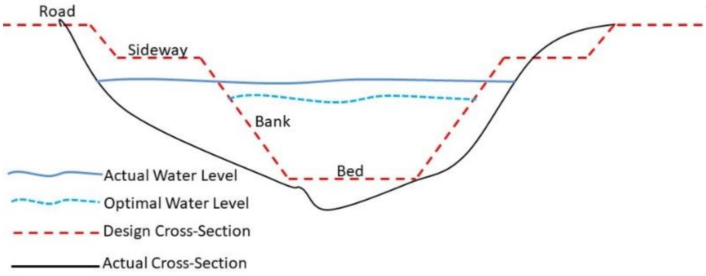

Fig 4: Schematic of the Actual and Design cross-sections of a typical canal in the Delta [70]

Fig 5: Main Drainage Canals in the Delta [55]

Those extensive and expansive networks frequently pass through or near settlements lacking efficient waste disposal systems and with almost no connectivity to sewage systems. The waterways are always under threat of clogging affecting their water flow efficiency and introducing pollutants mixing in with their waters changing its overall quality. This situation is exasperated by the high population density & growth rates in the Delta that results in the production of more waste. [70]

3- Change Detection Study

To observe the urban expansion across the Nile Delta, Landsat imagery was used for a change detection study from 1984 till 2018 with the aim of identifying the rates of urban growth, the growth patterns, and the apparent direct effects on the Delta.

To handle a change detection analysis on the Nile Delta across several decades required utilizing satellite imagery that covers the region since the latter half of the 20th Century. That was possible through the imagery provided through the Landsat mission that was first launched in 1972. [72]

The images were collected through the online archives of The Unites States Geological Services USGS of Landsat missions imagery that could be accessed through their online apps Global Visualization Viewer GloVis & EarthExplorer EE.

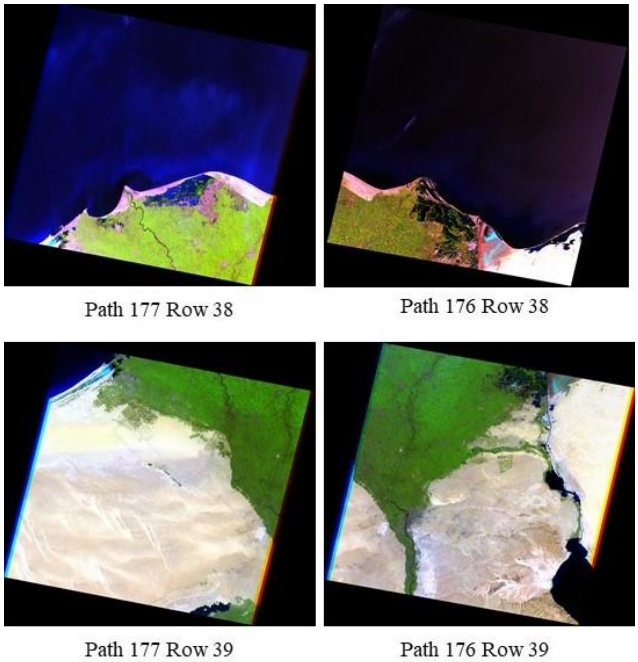

Fig 6: The Typical Four Scenes of Landsat Imagery covering the Nile Delta

Landsat composite image of bands 5-4-1 [SWIR (Short Wave Infra-Red) (5), NIR (Near Infra-Red) (4), blue (1)], Based on [30]

The change detection analysis for the Nile Delta region was carried out by processing 20 LandSat Imagery scenes to create 5 time-steps: 1984, 1990, 2000, 2010, & 2018. All acquired scenes were level-1 processing (either L1TP or L1 GT) which provide imagery that is radiometrically calibrated and orthorectified using ground control points and digital elevation models DEM, & All acquired scenes were with zero percentage cloud coverage.

The acquired scenes were then processed (Fig 7) using the remote sensing software ENVI 4.5 [73] & ENVI 5.3 [74] following the subsequent procedure:

- **Pre-Processing (Stacking & Atmospheric Correction)**

All spectral bands in each scene was stacked together excluding both the panchromatic bands (if available) as it offered no extra remote sensing data, and the thermal band as it is not useful for the next steps. Then Atmospheric Correction was carried out on the stacked scenes to remove the scattering and absorption effects caused by Aerosols, water vapor in the atmosphere, clouds, and cloud shadows. The scenes were radiometrically calibrated for reflectance and then algorithms for Dark object subtraction DOS were carried out.

- **Defining Classes & Regions of Interest ROI**

Four main landuse classes were decided to cover the typology of the Nile Delta region: Agriculture, Desert, Urban, & Waterbodies.

Region of Interests ROI were defined manually on each individual scene based on visual assertions of composite images.

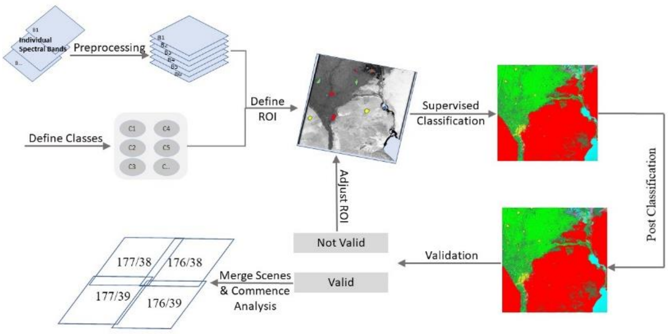

Fig 7: Processing steps of Landsat Scenes for Change Detection Analysis

- **Supervised Classification**

Once all ROIs have been adequately defined for any given Landsat scene, they are used to run “Maximum Likelihood” supervised classification algorithms to produce a fully landuse classified imaged.

- **Post Classification Run**

The classified images were then systematically inspected visually against the original Landsat scenes for errors and discrepancies. Any noticeable error was then corrected manually.

- **Validation**

For validation and accuracy assessment of the classified scenes, they were assessed through Kappa Coefficient (K) Analysis. A balanced stratified Sample of all landuse classes is created for each scene based on confirmed ground truth points by defining ROIs and then this sample is compared against the supervised classified scene through applying the “Confusion Matrix” tool. All Landsat scenes shown acceptable K values; between 0.84 and 0.93 for all scenes.

- **Aggregating classes & Moving to ArcGIS**

Finally, each four classified scenes of each time step (1984, 1990, 2000, 2010, 2018) were merged to form the whole of the Nile Delta. Then the merged scenes were exported to ArcGIS 10.2 [75] for further analysis.

4- Results

4.1- Rates of Urban Growth

By inspecting the classified scenes of the Delta from 1984 to 2018 (Fig 8) (Table 2), it shows that the urban growth encroaching on the agricultural land in that period amounts to ~ 1,465 km^2 (~348,783 Feddans); ~ 81.3 % of it since the start of the 2000s with ~ 41.5 % between 2010 & 2018.

The rate of the urban growth fluctuates greatly in those four decades corresponding to legislative & political changes. Following the introduction of the punitive measures section to the Agrarian law in 1984, the yearly growth rate till 1990 was less than 1.5 %.

Table 2: Urban Growth in the Nile Delta

Year	Urban Area (Km^2)	Growth (% from 1984)	growth *“from last”* (km^2)	Average Growth/year		Average Yearly Growth Rate (%)
				Km^2	Feddan	
1984	811.27	100		--------		--------
1990	882.42	108.77	71.15	11.86	2,823.43	1.46
2000	1084.92	133.73	202.50	20.25	4,821.34	2.29
2010	1666.91	205.47	581.99	58.20	13,856.87	5.36
2018	2276.16	280.57	609.25	76.16	18,132.54	4.57
	Total growth		1464.89			

But from 1990 till 2000, the growth rate increased by around 50% as the pressure from the population growth, defaulting housing market and decreased economic viability of agriculture holdings increased. Almost 19 % of all agricultural land lost occurred between 1984 & 2000, ~ 40% from 2000 till 2010, and over 41% from 2010 till 2018.

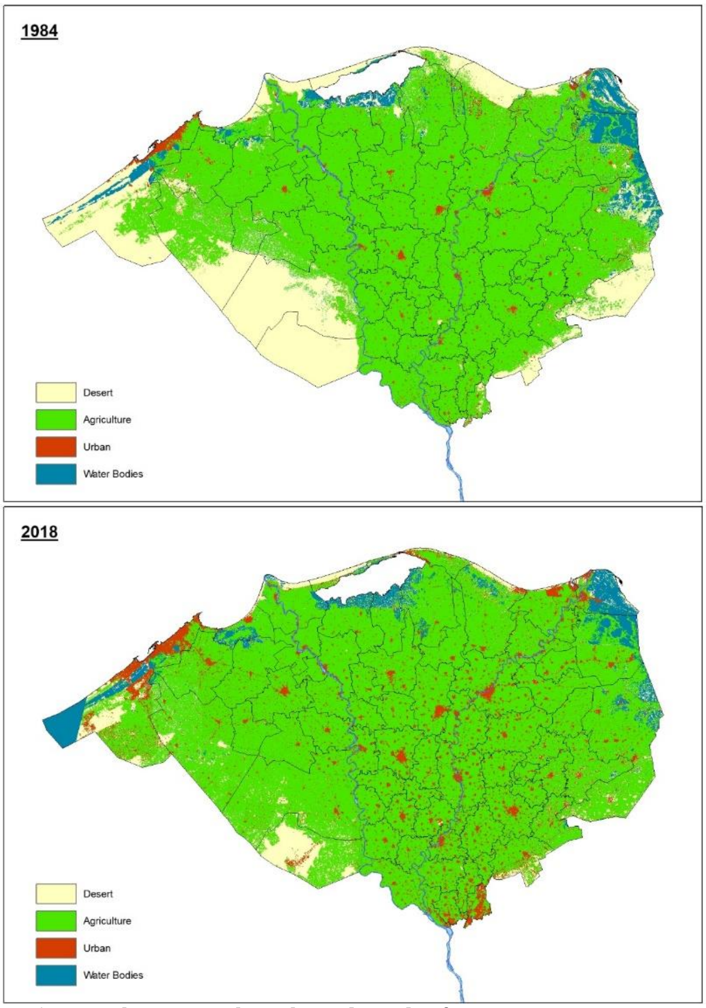

Fig 8: Urban Growth in the Nile Delta from 1984 to 2018

4.2- Observed Patterns of Urban Growth

Through visual observation of the various time series obtained from the classified imagery, the pattern of urban growth could be discerned.

The city of Banha; the capital of Qalioubia Governorate (Fig 9) was chosen for observation. The city lays to the north of

Cairo, along the Damietta branch with a variety of both large & minor villages bordering it.

Observing the patterns of growth in the region from 1984 till 2018 (Fig 10) shows:

a) The city of Banha is initially growing by filling in the gaps inside its fabric. At the same time the few villages to its North is also doing the same and filling in the gaps between each other at a progressive speed. Then the city and the agglomerated villages to the North move on to fill in the gap between each other. At the same time the two villages facing Banha on the East side of Damietta Channel are growing along & towards the channel in what seems like an attempt to be a twin to the city. It could be assumed that the growth in all this area served as housing & services expansion for the city itself

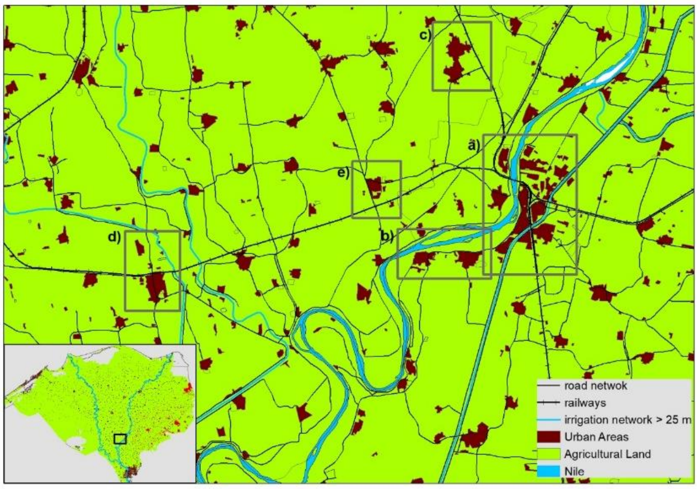

Fig 9: Banha and its surrounding villages
produced using [76]

b) The two villages immediately to the South East of Banha and laying along a connecting road. The two villages grow towards each other and to the south continuously through the time series but the growth towards Bahna itself at the vicinity is very slow.

c) The two villages lay on different roads but the mass of both were almost touching. They grow towards each other in a non-leaner fashion till they merge and then they expand the distinction between both villages is blured as the agglomerated mass start to look like one entity. Then they start to grow linearly on both roads to fill the gap they created by merging.

d) A main village lay at the intersection of several roads with a main road passing right in its middle and a train track right on its north edge. A small village is to the north of the track. Both villages start to grow towards each other despite the train tracks separating them. Once both their masses join, they start to grow along the sides of the roads and train tracks.

e) the village is wedged between the main road coming from Banha and a secondary road. To the south lays the train tracks. The village first grows on the secondary road heading towards the train tracks. Then slowly on the main roads towards Banha.

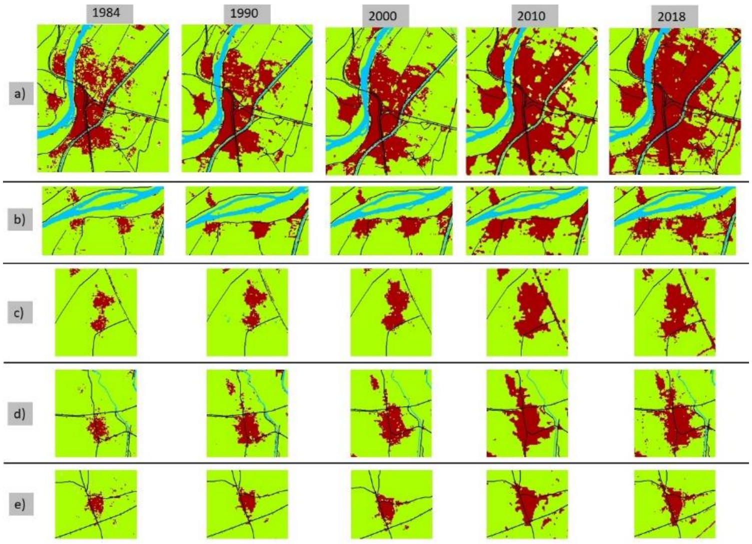

Fig 10: Growth patterns around the Region of Banha
produced using classified LandSat Imagery from [30], [76]–[83]

From those observation it could be seen that:

- The growth is usually linear with a tendency to grow along roads, canals and even train tracks.
- The tendency to grow towards the closest settlement and aggregate with it to form a bigger entity.
- Although a city would grow towards the villages in its immediate vicinity which in turn would grow towards the city, other village –outside that zone of influence– don't usually take the initiative to grow towards it.
- The flow of growth typically starts by filling the vacant lots and small agricultural patches within the town or village, then it starts to spread-out, along an existing road or waterway and preferably in the direction of the nearest settlement.
- There seem to be a form of preference when encroachments on agricultural land occur where the attractiveness of any land is apparently decided base on several obscure criteria, which seems to include overall location, proximity to another settlement, road network, waterway network…. etc.

4.3- Perceived Effects of the Urban Growth

It is evident that the Delta endures many adverse effects due to such massive urbanization across its prime agricultural lands. The loss of such lands is obviously the most apparent effect. And, with every parcel tuned to urban use, an agriculture holding either gets smaller or vanishes, thus increasing the ownership fragmentation while also increasing the physical fragmentation due to the encroachment.

Observing the extent of urban growth since 1984 till 2018 as overlaid on the governorates of the Delta (Fig 11) shows that except for one governorate all show huge to medium urban growth.

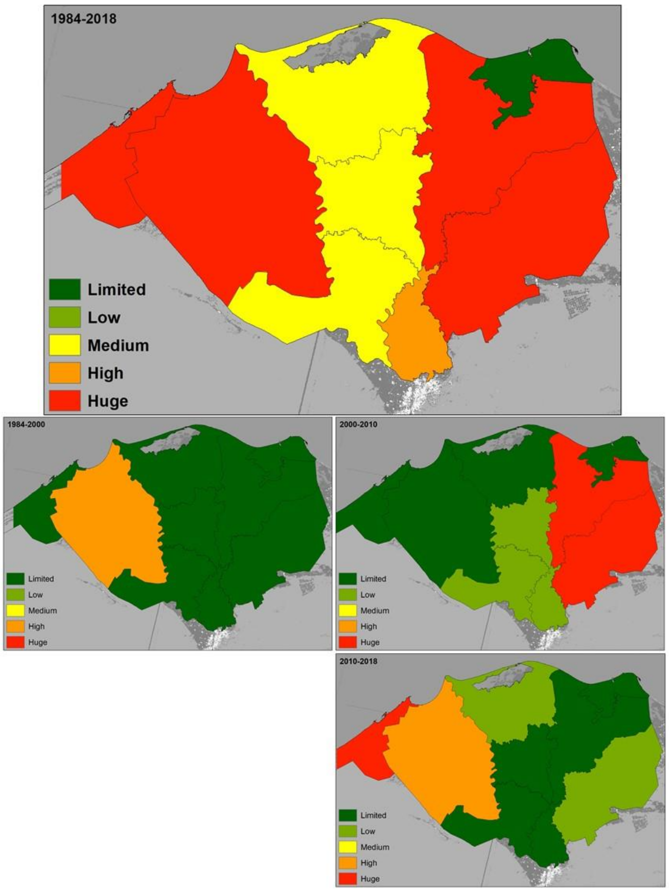

Fig 11: Urban Growth Levels over the Delta Governorates from 1984 till 018

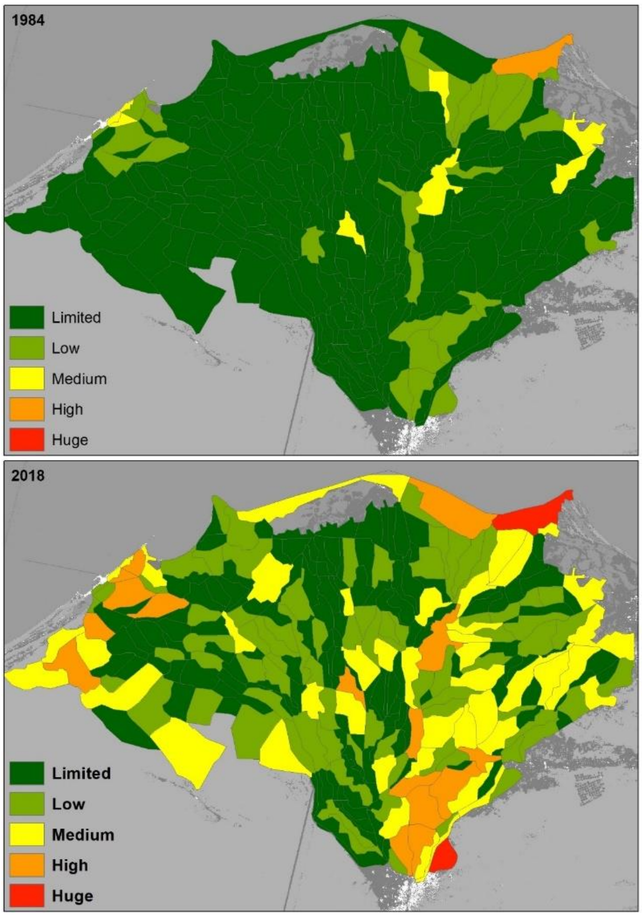

Fig 12: Urban Concentration spread over the CUs of the SIWARE model

From 1984 till 2000, Behera Governorate show high growth while all the other governorates show relatively limited urban growth. From 2000 till 2010, Both Dakahlia & Sharkia governorates show huge urban growth with limited to low urban growth in the remaining governorates. From 2010 till 2018, Alexandria shows huge growth followed by Behera showing high levels of growth while the remaining governorates show limited to low levels urban growth.

The cumulative effect of that growth is that from the five governorates facing the Mediterranean Sea, three show huge levels of urban growth (Alexandria, Behera, & Dakahlia) and one (Kafr-El-Sheikh) shows medium levels. Considering the risk of sea water intrusion that faces the Delta region as a whole and that one of the prime strategies to combat it is preserving the agricultural land in the North and focus especially on rice plantations, such levels of urban growth actually put the entire Delta region at risk of raising soil salinity.

On a similar note, managing the soil salinity in the Delta and preserving & improving the agricultural land productivity, depends in a great deal on the water management handled through the SIWARE model. When overlaying the overall urban concentration over the Calculation Units CU of the model (Fig 12), the CUs have limited urban presence in the 1984 when the model was first created but by 2018, ~6% of the CUs show huge to high concentration levels, ~ 16% show medium levels, and ~28% show low levels.

A parameter of defining each CU when the model was created is the amount of agricultural land it encloses, with that amount diminishing the efficiency of the calculations carried by the model should show a drop which would affect the efficacy of the water management process and in turn would affect the soil salinity.

On another level, a lower agricultural area should correspond to lower irrigation requirements. But since the design cross-section of the canals are already engineered to carry a specific minimum load of irrigation water from the start of canal to its end to support a considerably larger agricultural area, this would eventually lead to wasting a considerable amount of irrigation water.

The same waterways will also be subject to great amounts of pollution as:

- The Egyptian villages have no functioning solid waste management systems.
- less than 6% of the villages in Egypt, and only around 29% of the cities are connected to sewage systems.[14], [43] and this unhandled sewage always end up in the canals. [70]
- The population in the Delta has increased since 1986 till 2018 by 227%. The population density on the Delta is considered one of the highest densities worldwide.

- The built-up area stretching along waterways has increased from 1984 till 2018 by 344% (Fig 13).

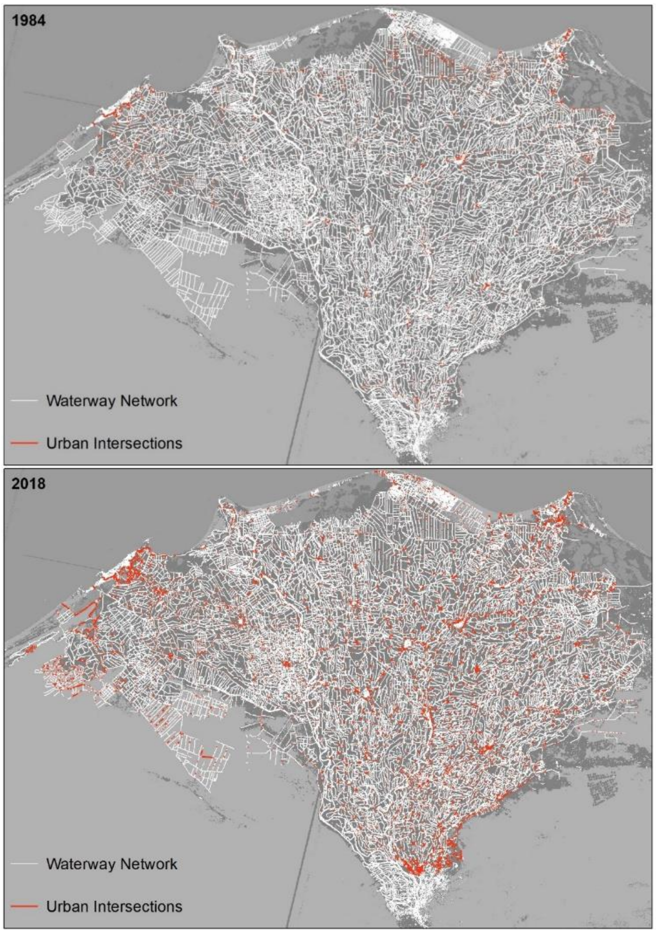

Fig 13: Urban intersections with the Waterway Networks between 1984 & 2018

As such, huge volumes of waste & sewage would be produced by the high density of population in the region. This waste would be dumped in the waterway network to which it can gain easy access. Thus, this contamination would eventually return to the prime soil affecting crop growth, overall productivity, & quality.

5- Discussion

The Nile Delta represents a multidimensional system where in the background lays prime agricultural land & complex waterway network and in the foreground an intricate constantly growing human habitat network with a bureaucratic legal system.

The agricultural land needs continuous monitoring and conservation to preserve its crop yields while the waterways network strives to keep up with the in-field water demands and are under pressure from decreased efficiency and growing contaminant loads. All the while, the economic viability and feasibility of the agricultural land is constantly declining.

The human habitat is a network of growing cities & villages with questionable living conditions that always infringe on prime agricultural land while creating a multitude of waste materials that end up as pollutants that find their way to the waterways system and ultimately to the agricultural fields.

The bureaucracy has attempted to stop the infringement on the agricultural land with legislative penal measures that had little effect under the pressure of a huge population and with planning projects that eventually infringed on more land. Meanwhile, the government aimed to increase the economic feasibility of agriculture by introducing improved practices for irrigation, drainage & creating better crops.

Meanwhile, it totally ignored fragmentation as a main issue of the Delta with no efforts to confront this problem; by either working on lifting\ raising the ownership ceiling or working on consolidating the land holdings or both.

As a result, the agricultural fragmentation is becoming more evident across the region with smaller farms emerging, infringements dividing otherwise connected land parcels, and more contaminants leaking into the soil. A situation that should explain why land productivity is decreasing despite all actions taken that should have improved it greatly. Not to mention the increased risk of sea water intrusion and subsequently the soil salinity due to the high concentration of the urban growth towards the north region of the Delta.

Observing the growth of cities and villages in the Delta through the classified images shows that growth moves along linear networks e.g.: roads, train tracks, & waterways though with no apparent cause behind the direction of growth. It would try to fill the gaps between nearby settlements; villages would try to aggregate together forming a larger mass though at the same time would not take the initiative to grow towards a nearby city which would seem to be a more preferable option.

A study of the driving forces of urban growth in play across the Delta is needed to comprehend the dynamic of this never ending growth as a means of formulating working plans to stave such growth in the future.

6- References

[1] I. Overeem and J. P. M. Syvitski, “Dynamics and Vulnerability of Delta Systems,” 2009.

[2] J. M. Coleman, O. K. Huh, and D. Braud, *Major world deltas: A perspective from space*. 2003.

[3] P. Harris *et al.*, “Ch.44 Estuaries and Deltas,” in *The First Global Integrated Marine Assessment*, vol. 1, Cambridge University Press, 2016, p. 9.

[4] D. A. Edmonds *et al.*, “Analysis of human habitation on river deltas,” *EGU Gen. Assem.*, vol. 1, p. 9, 2017.

[5] United Nations, “World Population Prospects - 2017 -Volume II: Demographic Profiles,” New York, 2017.

[6] FAO, “Country Fact Sheet: Egypt,” 2010.

[7] Aquastat, “AQUASTAT - FAO’s Information System on Water and Agriculture,” 2016.

[8] CAPMAS, “Egypt in Numbers,” 2018.

[9] Egypt's Information Portal, "Geographical Location." [Online]. Available: http://www.eip.gov.eg/aboutegypt/GeoInfo.aspx. [Accessed: 07-Nov-2018].
[10] Aquastat, "Country fact sheet : Egypt," 2017.
[11] Food and Agriculture Organization of the United Nations, "FAOSTAT - Egypt." [Online]. Available: http://www.fao.org/faostat/en/#country/59. [Accessed: 07-Nov-2018].
[12] A. I. K. El-Hefnawi, "Protecting'agricultural land from urbanization or 'managing'the conflict between informal urban growth while meeting the demands of the communities (lessons," *...on L. Dev. Urban Policy ...*, 2005.
[13] A. A. Afify, S. M. Arafat, N. M. Afify, and I. F. Ahmed, "Retreating rate estimation of the fertile alluvium in Nile Delta under the urban encroachment, using remote sensing data and GIS techniques," *16th Int. Symp. Remote Sens. Spat. Inf.*, 2008.
[14] CAPMAS, "Egypt in Numbers," 2010.
[15] E. Alnouby, "The government releases new law in days to confiscate 'turned to urban' agricultural lands," *Alyoum Alsabea*, 20-Nov-2014.
[16] S. Metwaly, "Egypt loses 4000 feddans monthly to corruption," *Almasry Alyoum*, 29-Oct-2015.
[17] I. Soliman, *Sustainable Agricultural Development*. Springer International Publishing, 2015.
[18] EEAA, "Egypt-State of the Environment-2016," Egypt, 2017.
[19] R. Said, *THE RIVER NILE: GEOLOGY, HYDROLOGY AND UTILIZATION*. Pergamon Press, Oxford, 1993.
[20] J. Coleman, O. Huh, and D. Braud, *Major world deltas: A perspective from space*. 2003.
[21] B. A. Zeydan, "THE NILE DELTA IN A GLOBAL VISION," *iwtc.info*, pp. 31–40, 2005.
[22] M. E. D. Hereher, "Monitoring spatial and temporal changes of agricultural lands in the Nile Delta and their implications of soil characteristics using remote sensing," THE UNIVERSITY OF ARIZONA, 2006.
[23] A. Gupta, *Large Rivers: Geomorphology and Management*. John Wiley & Sons, 2008.
[24] A. Richards, *Egypt's agricultural development, 1800-1980 : technical and social change*. Boulder, Colo.: Westview Press, 1982.
[25] A. Elrafey, *Mohamed Ali's Era*, Fifth edit. Cairo: Dar Alma'aref, 1989.
[26] A. Alheta, *History of Egyptian Agriculture in Mohamed Ali's Era*. Cairo: Egyptian Public Agency for Book, 2012.
[27] M. Mostafa, "Egyptian Agriculture in Mohamed Ali Basha's Era; 1805-1849." Agriculture Economy-Monofia University, Monofia, 2014.
[28] P. H. Bent, "Agrarian change and industrialization in Egypt, 1800-1950," *Colloq. Int. Rech. Régulation La théorie la régulation à l'épreuve des Cris.*, pp. 1–12, 2015.
[29] Interim Trusteeship Authority, *Agrarian Reform law*. Egypt, 1952.
[30] USGS, "LandSat Imagery," 1984.
[31] Interim Trusteeship Authority, *Rent Value reduction for places law*. Egypt, 1952.
[32] Egyptian Ministries Council, *Tax on built real state Law*. Egypt, 1954.
[33] United Arab Republic, *Reduction of Places' Rent value in the Southern Region Law*. Egypt, 1958.
[34] United Arab Republic, *Rent Value Reduction for Places law*. Egypt, 1961.
[35] Egyptian Parliament, *Rent Value Reduction for Places Law*. Egypt, 1962.
[36] Egyptian Parliament, *Rent Value Reduction for Housing Law*. 1965.
[37] President of the United Arab Republic, *law no 50 year 1969; Establishing an ownership ceiling for family and individual to agricultural land and its par*. United Arab Republic: Official State Newspaper, 1969.
[38] S. Hagras, *Egyptian Agriculutre*. Cairo: Academic Library, 1996.
[39] I. Askora, "Urban Expansion and the Erosion of Agriculture land," in *Sustainability of Arab Cities and the secure tenure of housing and land and urban management*, 2005, p. 24.
[40] Egyptian Parliament, *Agrarian Law*. Egypt: Alamiria Press, 1966, p. 166.
[41] Egyptian Parliament, *Law no 59 for 1978 on "Amendments to Agriculture Law."* Egypt: Official State Newspaper, 1978.
[42] Deputy Military Ruler, *Decree 1 for the year 1996 on forbidding agriculture land Degradation & Dredging & Making buildings or constructions on it*. Egypt: Official State Newspaper, 1996, p. 2.
[43] M. ELsaid, "Planning for Sustainable Rural Development in Egypt," Ain Shams University, 2007.
[44] Ministry of Agriculture and Land Reclamation, "Annual agricultural statistics bulletin," Cairo, 2009.
[45] MLD, "Egypt; Administrative divisions," Cairo, 2014.
[46] CAPMAS, "Labor Force 1983," Egypt, 1983.
[47] FAO, "Irrigation in Africa in figures," 2005.
[48] CAPMAS, "Development of the agricultural sector 2014," 2014.
[49] The World Bank, "Agriculture, forestry, and fishing, value added (% of GDP) | Data." [Online]. Available: https://data.worldbank.org/indicator/NV.AGR.TOTL.ZS?locations=EG. [Accessed: 20-Nov-2018].
[50] I. H. Ibrahim and M. A. Soliman, "Existing urban vision for Egyptian villages " Positive & Negative characteristics " First : Tanah village urban studies : -," *Urban. pvs*, vol. 53, 2009.
[51] A. N. Hareedy and A. Deguchi, "Physical Transformation of Rural Villages Encompassed into Egyptian City Borders," *J. Asian Archit. Build. Eng.*, vol. 9, no. 2, pp. 379–386, 2010.
[52] CAPMAS, "The Important Indicators of the Comprehensive Survey of the characteristics of the Egyptian Rural Areas 2015," Egypt, 2015.
[53] CAPMAS, "Monthly Bulletin of Foreign Trade Data 2017," Cairo, 2018.
[54] A. H. Abdel Hadi, "Country Report on Egyptian Agriculture," *IPI Reg. Work. Potassium Fert. Dev.*

West Asia North Africa, p. 15, 2004.
[55] MWRI, "National Water Resource Plan 2017," Cairo, 2005.
[56] H. P. Ritzema, *Drain for gain: making water management worth its salt, Subsurface Drainage Practices in Irrigated Agriculture in Semi-Arid and Arid Regions*, no. January 2009. 2009.
[57] H. Kheir-El-Din and H. Heba El-Laithy, "Agricultural productivity growth employment and poverty in Egypt," *Work. Pap. Ser.*, vol. 129, no. 129, p. 34, 2008.
[58] T. H. . Kotb, T. Watanabe, Y. Ogino, and K. K. Tanji, "Soil salinization in the Nile Delta and related policy issues in Egypt," *Agric. Water Manag.*, vol. 43, no. 2, pp. 239–261, Mar. 2000.
[59] B. J. van den Broek, "Dutch Experience in Irrigation Water Management Modelling," Utah, 1996.
[60] I. SECRETARIAT, "EGYPT ' S EXPERIENCE IN IRRIGATION AND DRAINAGE RESEARCH UPTAKE EGYPT ' S EXPERIENCE IN IRRIGATION AND DRAINAGE RESEARCH UPTAKE," Rome, 2007.
[61] R. Smit, "Personal Communication on the Characteristics of SIWARE," 2011.
[62] T. A. Elbana, N. Bakr, and M. Elbana, "Reuse of Treated Wastewater in Egypt: Challenges and Opportunities," in *Unconventional Water Resources and Agriculture in Egypt*, A. M. Negm, Ed. Cham: Springer International Publishing, 2017, pp. 429–453.
[63] LER, "Classification of Agricultural land Resources based on the Productivity Grades of Crops (1981-1985)," Cairo, 1987.
[64] LER, "Classification of Agricultural land Resources based on the Productivity Grades of Crops (1986-1990)," Cairo, 1992.
[65] LER, "Classification of Agricultural land Resources based on the Productivity Grades of Crops (1991-1995)," Cairo, 1997.
[66] LER, "Classification of Agricultural land Resources based on the Productivity Grades of Crops (1996-2000)," Cairo, 2002.
[67] LER, "Classification of Agricultural land Resources based on the Productivity Grades of Crops (2001-2005)," Cairo, 2007.
[68] LER, "Classification of Agricultural land Resources based on the Productivity Grades of Crops (2006-2010)," 2014.
[69] LER, "Classification of Agricultural land Resources based on the Productivity Grades of Crops (2011-2015)," Cairo, 2018.
[70] A. A. Alfiky, "Fragmentation Analysis of the Nile Delta - A Development of Regional Planning Tool," Ain Shams University, 2019.
[71] G. A. H. Sallam, "The Assessment of Egypt's Subsurface Drainage System," in *Unconventional Water Resources and Agriculture in Egypt*, A. M. Negm, Ed. Cham: Springer International Publishing, 2017, pp. 27–58.
[72] USGS, "Landsat Satellite Missions." [Online]. Available: https://www.usgs.gov/land-resources/nli/landsat/landsat-satellite-missions?qt-science_support_page_related_con=2#qt-science_support_page_related_con. [Accessed: 17-Mar-2019].
[73] ITT, "Envi 4.5." ITT Visual Information Solutions, 2008.
[74] Exelis, "ENVI 5.3." Exelis Visual Information Solutions, Inc., a subsidiary of Harris Corporation, 2015.
[75] ESRI, "ArcGis Desktop 10." ESRI Inc., 2010.
[76] GOPP, "GIS database of the Nile Delta region." General Organization for Physical planning, Cairo, 2000.
[77] USGS, "LandSat Imagery," 1990.
[78] USGS, "LandSat Imagery," 1998.
[79] USGS, "LandSat Imagery," 2000.
[80] USGS, "LandSat Imagery," 2003.
[81] USGS, "LandSat Imagery," 2010.
[82] USGS, "LandSat Imagery," 2014.
[83] USGS, "LandSat Imagery," 2018.

7- Authors

Abdulmoneim Alfiky received his B.Sc. in Urban Planning and Design in 2001 from the Faculty of Engineering – Ain Shams University, where he subsequently became a teaching assistant in the Dept. of Urban Planning and Design. In 2008 he received his M.Sc. on the topic of Urban Environmental management from Ain Shams University. His professional experience focuses on strategic and regional planning in rural areas of the Egyptian Nile Delta. He actively participated in several TEMPUS project between Ain Shams University and various European universities. Currently he is working on his PhD on effects of urban and rural sprawling on the agricultural lands in the Nile Delta under joint supervision from Ain Shams University & University of Stuttgart. He joined the IUSD Course Coordination Team at Ain Shams University in 2013. And Since August 2014, he holds the position of the IUSD Projects Coordinator at Ain Shams University.

Mohamed Salheen is a professor at Ain Shams University. He obtained his BSc in Urban Planning and Design in 1993 from Ain Shams University, Cairo. He was appointed as teaching staff at the department and later received a PhD scholarship to obtain his PhD in Urban Design from Edinburgh College of Art, UK in 1997 with a thesis on "Comprehensive Analysis Approaches in Urban Settings". From 2001 until 2014 he acted as an assistant and associate professor at Ain Shams University teaching and supervising multidisciplinary topics. Developing a clear research line in the field of Integrated Planning and Design, he then became the first professor of Integrated Planning and Design in Egypt. He has coordinated several international cooperation projects with Universities in Germany, Sweden, Austria and Denmark. He is a member of the EU Higher Education reform Experts (HEREs) Team, contributing to various workshops and seminars on internationalization and harmonization of Higher Education. Salheen is also active in practice and consultation working with GIZ, UN-Habitat, UNEP and UNDP as well as other national and regional organizations in the fields of strategic, environmental and integrated planning and design.